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The Peace Mediator effect: Heterogeneous agents can foster consensus in continuous opinion models

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ABSTRACT

Statistical mechanics has proven to be able to capture the fundamental rules underlying phenomena of social aggregation and opinion dynamics, well studied in disciplines like sociology and psychology. This approach is based on the underlying paradigm that the interesting dynamics of multi-agent systems emerge from the correct definition of few parameters governing the evolution of each individual. Into this context, we propose a particular model of opinion dynamics based on the psychological construct named "cognitive dissonance". Our system is made of interacting individuals, the agents, each bearing only two dynamical variables (respectively "opinion" and "affinity") self-consistently adjusted during time evolution. We also define two special classes of interacting entities, both acting for a peace mediation process but via different course of action: "*diplomats*" and "*auctoritates*". The behavior of the system with and without peace mediators (PMs) is investigated and discussed with reference to corresponding psychological and social implications.

Keywords: opinion dynamics, complex systems, peace mediation, social psychology, cognitive dissonance

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I. INTRODUCTION

In recent years we have seen the emergence of a new breed of professionals broadly called Peace Mediators, PMs for short, involved in the process of peace (re)construction. They are usually deployed in countries torn by conflict or post-conflict areas in order to create conditions for sustainable peace. PMs actions aim to reduce the fragmentation among different parts of the society until a widespread consensus is achieved and peace can be maintained.

Our model is based on the assumption that it is possible to study the evolution of a social phenomenon directly by considering a few attributes of the individuals coupled by specific interaction rules. For these reasons, we adopt an agent based model, in which local rules are inspired by the *cognitive dissonance* [1], a cognitive construct that rules the evolution of human social cognition [2]. According to the Cognitive Dissonance Theory, when unknown individuals interact, they experiment an *internal conflicting state* because of their reciprocal lack of information. In order to avoid the cognitive dissonance, individuals adopt heuristics strategies with the aid of *mental schemes* [3], that is, symbolic and synthetic representations built up through inferential, imaginative and emotional processes. Because mental schemes can be upgraded in real time during interactions with other individuals, they are utilized as a guidance for quick decisions in stereotypical situations. For instance, the mutual affinity is the mental scheme employed by agents to overcome the lack of information about the others (that is, the cognitive dissonance) and to perform the optimal choice in terms of opinion production. In particular, two heuristic strategies are mainly employed:

A) if the affinity towards the interacting partner is below some threshold, the individual tends to crystallize his/her actual opinion, while for higher values of affinity he/she will change opinion in the direction of the partner's one;

B) if the opinion difference between the two interacting agents is below a critical value, then each one will increase his/her affinity towards the partner, otherwise the affinity scores will decrease.

These two ways of acting are modulated by external factors, as for example the possibility of interacting given by the social system, and especially by internal ones, such as the *openness of mind* and the *confidence.* The openness of mind is the limit of permissiveness that an individual introduces interacting with other people, and allows to ignore the perception of incompatibilities existing between oneself and the others; consequently, it makes possible to interact with individuals having very distant opinions. On the other hand, the confidence is the minimal reputation an individual requires to a stranger to accept instances from him/her. In practice, I will be more available to uniform my opinions with the opinions of someone with a large affinity with myself. Moreover, affinity acts as a long term memory in which individuals can store information useful to solve similar future situations.

By formalizing agents in such a way, we obtain a dynamical population where interacting agents share their opinions by trying to maintain an acceptable level of dissonance. The asymptotic states of such system are either a global consensus (i.e. into an hypothetical opinion space, a mono-clustered state) or a social fragmentation (i.e. crystallization of no longer interacting clusters of opinion). Of course, in the vision of the PMs, social fragmentation has to be considered a dangerous state, since once obliged to interact, the low level of mutual affinity and the differences in opinion, may lead to strong social contrasts between these agents. For this reasons, the goal of the PMs can be translated into a reduction of the social fragmentation, namely into a reduction of opinion distances among agents into the opinion space.

The aim of this paper is to present two possible models of PM behavior. In the first case, we emphasize principally the skill of interacting and negotiating with people along large opinion distances. We label these PMs as "*diplomats*" and we tag their most prominent characteristic as a larger openness of mind. Classical examples are actual diplomats, transactors, intermediaries, etc. On the other hand, we consider as another fundamental attribute of a PM his/her reputation. Hence, we label this PM figure as an "*auctoritas*" ("authority"), which is characterized by an established good reputation and the aptitude to influence the society by their prestige. For example, we can set in this category Mahatma Gandhi and Nelson Mandela.

Targets of this work are to obtain a mathematical representation of both PM figures and to investigate by means of numerical simulations how they can affect a formalized social system of *normal* agents in order to reach a widespread social consensus.

The paper is organized as follows. The next section is dedicated to describe the model. Then, in third section we present the numerical results. Fourth and fifth sections are devoted to analytical considerations and theoretical discussion, respectively. Finally, in the last section we will sum up and talk about future perspectives.

II. THE MODEL

We approach the problem by means of the tools and methods of Sociophysics [4, 5]. In particular, the adopted model, without PMs, has already been studied in previous studies [2, 6, 7]: indeed, we are going to refine it in the present paper. Therefore, we briefly recall its main features. The model is characterized by a continuous opinion and a random binary encounter dynamics, as in the Deffuant Model [8, 9], which ours is inspired to (at least the part concerning the evolution of the opinions). We consider a system made up of N autonomous agents, the individuals, each one identified by the index $i = 1, \ldots, N$ and characterized by the two (constant) parameters ΔO_c^i and α_c^i, which are the openness of mind and the confidence[10], respectively. Moreover, each agent i is in general described by the two internal variables O_i, its opinion, and α_{ij} ($j = 1, \ldots, N;\ j \neq i$), its affinity towards the other agents, which vary in time. All ΔO_c^i, α_c^i, O_i and α_{ij} are real numbers ranging in the interval $[0, 1]$. The internal variables evolve self-consistently during time evolution.

More precisely, let us consider an agent i interacting with another agent j: then, the opinion O_i and the affinity α_{ij} (*i.e.*, the affinity i feels towards j) are updated as follows [2, 6, 7]:

$$O_i^{t+1} = O_i^t - \mu\ \Delta O_{ij}^t\ \Gamma_1(\alpha_{ij}^t) \tag{1}$$

$$\alpha_{ij}^{t+1} = \alpha_{ij}^t + \alpha_{ij}^t\ [1 - \alpha_{ij}^t]\ \Gamma_2(\Delta O_{ij}^t) \tag{2}$$

where the activating functions Γ_1 and Γ_2 read, respectively:

$$\Gamma_1(\alpha_{ij}^t) = \Theta(\alpha_{ij}^t - \alpha_c^i) \tag{3}$$

$$\Gamma_2(\Delta O_{ij}^t) = 1 - 2\ \Theta(|\Delta O_{ij}^t| - \Delta O_c^i) \tag{4}$$

being $\Delta O_{ij}^t = O_i^t - O_j^t$ the difference at time t between the two opinion values of the interacting partners, μ a convergence parameter and $\Theta(\cdot)$ is the Heaviside step function. In practice, an agent i interacting with another agent j changes its opinion only if its affinity towards j is larger than its own confidence α_c^i: in that case, the opinion updates according to the already mentioned Deffuant rule. Analogously, agent i evolves the affinity towards j only if their opinions differ less than i's openness of mind. If this is the case, the updating of α_{ij}^t is not linear: the logistic term keeps the affinity in the interval $[0, 1]$; moreover, it maximizes the change in affinity for pairs with $\alpha_{ij} \simeq 0.5$, corresponding to agents which have not come often in contact. Couples with $\alpha_{ij} \simeq 1$ (resp. 0) have already formed their mind and, as expected, behave more conservatively. Anyway, a more thorough justification of these rules, also from a psycho-social point of view, can be found in reference [2].

At each elementary time step the two interacting agents are selected as follows: the agent i is drawn with uniformly distributed probability from the population, whilst agent j is the one which minimizes the social metric

$$D_{ij}^t = d_{ij}^t + \eta(0, \sigma)\ , \tag{5}$$

composed by the two terms, respectively the *social distance*

$$d_{ij}^t = \Delta O_{ij}^t (1 - \alpha_{ij}^t) \qquad j = 1, ..., N \qquad j \neq i \tag{6}$$

and the gaussian noise (η) with mean value zero and variance σ (which is also called *social temperature* [3]), modulating the mixing degree in the population. The above formulas mean that two agents are more likely to interact when their opinions have a small difference and/or their affinity is larger, but, due to the social temperature, it is always possible an interaction between two individuals with very different opinions or very small reciprocal affinity. More precisely, in absence of social noise ($\sigma = 0$), an agent will surely interact with the stranger which minimizes the social distance d_{ij}^t, with $\sigma \to +\infty$ the interactions are completely random, for intermediate values most matches will be between individuals at short social distance, with few long-range interactions. A time unit is made up of N single elementary time steps (Montecarlo steps).

Being the ultimate goal of PMs the reduction of social fragmentation, both *diplomats* and *auctoritates* will act in this direction, but via different courses of action. *Diplomats* are assumed to have a larger ΔO_c then *normal* agents and consequently they can interact in the opinion space with far away agents. According to Eq. 1, this way of acting will lead to an increase of the individuals affinity towards *diplomats*. On the other hand, *auctoritates* are assumed to employ their notoriety; this is translated in our model by imposing that all agents have a larger affinity value towards them, directly promoting the convergence into opinion space.

III. NUMERICAL SIMULATIONS

Simulations are performed with following parameters. N is fixed once for all to 100, including PMs. The social temperature σ, the affinity threshold α_c and the convergence parameter μ are fixed once for all, respectively at 0.003, 0.5 and 0.5. *Normal* agents have a $\Delta O_c = 0.2$, while for *diplomats* $\Delta O_c = 0.5$. Entries in the affinity matrix α are initialized between *normal* agents with uniformly distributed probability in $[0, 0.5]$, while entries corresponding to *normal* agents towards *auctoritates* are set at 0.75. We have chosen the above values of the parameters as the most reasonable and conservative possible, in order not to have an unbalanced system (agents not too mind-opened nor too mind-closed, affinity distribution not too narrow nor too broad, etc.); moreover, the chosen value for σ allows the existence of interactions among socially distant agents maintaining higher probabilities for matches between socially closer individuals. Anyway, we have also verified that the results we are going to present in this section are rather robust by varying such values: unless extreme values are chosen, the system behavior qualitatively does not change.

We have considered both the fraction of PMs over the entire population and their distribution in the opinion space as the relevant control parameters, hereby measuring the mean number of survived clusters at the equilibrium over 100 runs. The range of employed PMs is from 5% to 50% in steps of 5%. We remark that, so as formalized, the increase of fraction of PMs can corresponds respectively either to a fixed number of PMs having to do with smaller group, or to a population having a higher mean ΔO_c (*diplomats*).

Runs are stopped when the system converge to an equilibrium asymptotic state. We define such a state is reached when the affinity matrix will no longer change. We know that for communities larger than 20 agents, the system converge with respect to the opinion before than respect to the affinity [7]. Hence, when affinity reaches a state where it no longer evolves, the whole system, i.e. also the opinion, will freeze. Such asymptotic state will be characterized by the number of clusters in the opinion dimension.

Scenarios. The behavior of the two PMs figures are separately studied in a starting system which entries of opinion vector O are initialized uniformly spaced in $[0, 1]$. *Diplomats* are distributed along the opinion space by substituting them to the already initialized *normal* agents and according with the following modalities. In the "*uniform*" distribution *diplomats* are spread along the opinion space with uniformly distributed probability; in the "*gaussian*" one with a gaussian distribution (mean 0.5, standard deviation 0.2); in the "*bimodal*" distribution they are inserted with a bimodal distribution, that is, half of them with initial opinion equal 0.25 and half equal to 0.75.

The same opinion vector initialization and strategy distribution are used for *auctoritates*, with the addition of a "*delta*" strategy in which all *auctoritates* are grouped around the center of the opinion space, namely around 0.5.

The "*two opposing factions*" case - Hereby we propose an application of the model. We consider a starting opinion space in which agents are divided into two large clusters, such that their respective opinion distances are larger than the opinion threshold of any single agent ("bi-clustered system"). In such a way, there is no possibility of interaction between agents belonging to the two different groups. Nevertheless, *diplomats* are able to interact with both factions because of their large openness of mind, while *auctoritates* can attract individuals because of their high reputation. We thus compare the two different courses of action. In order to evaluate the effectiveness of their action, we tested every configuration with a different density of mediators, from zero up to 50% (of course, such a high presence of mediators does not take place in the real world, anyway it is useful to reach it for a better theoretical understanding of their role).

IV. RESULTS

Figure 1 shows typical trajectories into the opinion space of a system of *normal* agents (1a), a system influenced by *diplomats* (1b) and a system influenced by *auctoritates* (1c), respectively. While the system of *normal* agents quickly converge to a fragmented asymptotic state, the insertion of PMs increases the convergence time needed as so as the chances of obtaining a mono-clustered state. We remark the different courses of action of the two PMs. Because of the great ΔO_c value, *diplomat* increases affinity towards neighborhood, approaches partner and inclines it towards its own opinion. Agents inside the opinion bounds of *diplomat* have a larger probability of collapse in the same final position, and the *diplomat* has the possibility to explore the entire opinion space. On the other hand, an *auctoritas* tends to reach the equilibrium with the same opinion value with respect to the initial condition. In this latter case, the affinities of *normal* agents towards *auctoritates* trigger the convergence dynamics to monocluster.

Figure 2 resumes results relative to *diplomats*. The insertion of *diplomats* reduces the mean degree of fragmentation at equilibrium. Moreover, this reduction is linear and positively correlate with the fraction of employed *diplomats*. Although the three distribution strategies have similar trends (Fig. 2a), by augmenting the fraction of *diplomats*, the *gaussian* one tends to reach the greater number of mono-clusters at equilibrium (Fig. 2b, lower).

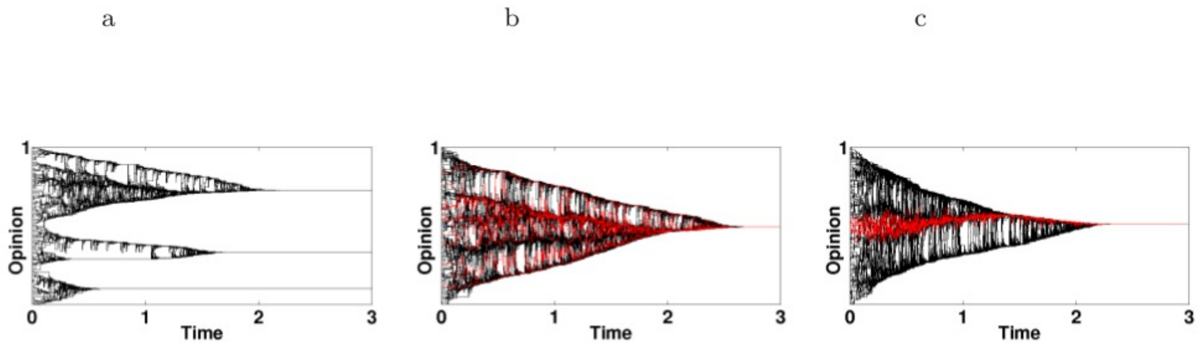

FIG. 1. Typical opinion trajectories. Each time step are 10^4 interactions. a) *Normal* agents (see ref. [2]); b) *Normal* agents (black) and *diplomats* (red); c) *Normal* agents (black) and *auctoritates* (red).

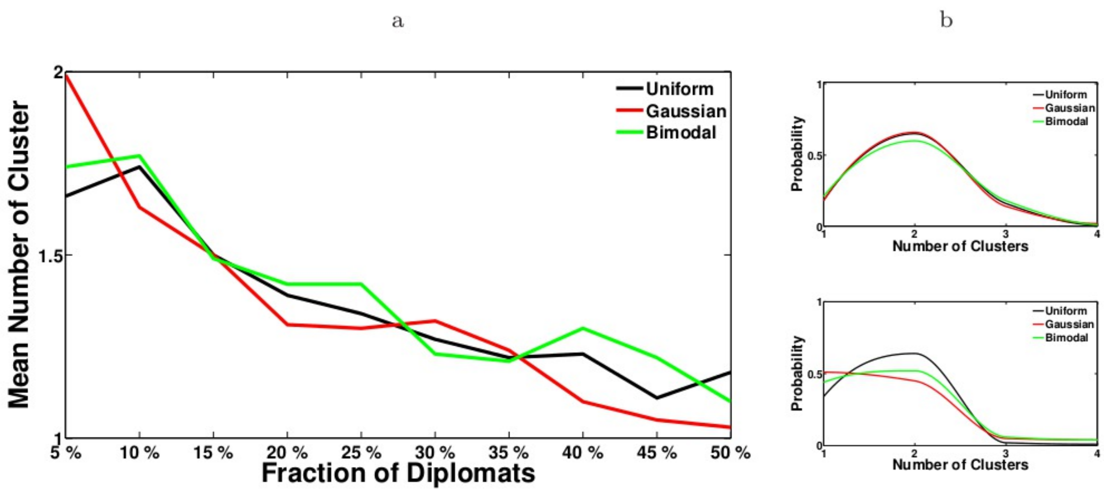

FIG. 2. Behavior of a system modulated by *diplomats*, for three different initial distributions. a) Mean number of survived clusters at the equilibrium as a function of the fraction of *diplomats*. b) Probability of having N clusters at the equilibrium in a single run, 5% of *diplomats* (upper figure), 50% of *diplomats* (lower); for sake of clearness, the histograms are interpolated by ninth degree polynomials (naturally, the effectively measured probabilities are in correspondence of integer values of the abscissas).

Figure 3 resumes results relative to *auctoritates*. Once more the insertion of PMs reduces the mean degree of fragmentation at equilibrium, but hereby the adopted distribution strategies substantially influence results of simulations (Fig. 3a). By varying the employed fractions of *auctoritates*, *gaussian* and, mainly, *delta* distributions show best trends in terms of convergence to a mono-cluster state. The *bimodal* distribution tends to converge to a bi-clustered state (Fig. 3b, lower).

Figure 4 shows results of insertion of PMs into a bi-clustered starting population (that is, a population where initially half population has opinion equal to 0.25 and the remaining half equal to 0.75); previous results are confirmed. *Diplomats* become efficacious only for higher fractions of employment and mainly with a *gaussian* distribution. *Auctoritates*, spread with either a *gaussian* or, above all, a *delta* strategy, assure the convergence to a mono-clustered asymptotic state since lower fractions of employment.

Opinion and affinity final distributions - Concerning the configuration of the opinions and affinities at the end of the dynamics, we verified that the former distribute so that the surviving ones are all equidistant, that is, if there is a monocluster the unique final opinion will be around 0.5 (see Fig. 1), if there are two cluster the survived opinions will be close to 0.25 and 0.75 (see Fig. 5), and so on. On the other hand, the final affinities distribute in the simplest way: agents belonging to the same cluster (*i.e.*, share the same final opinion) will have affinity equal to 1 towards each other, and practically to 0 if instead they end up with different opinion, as shown in Fig. 6.

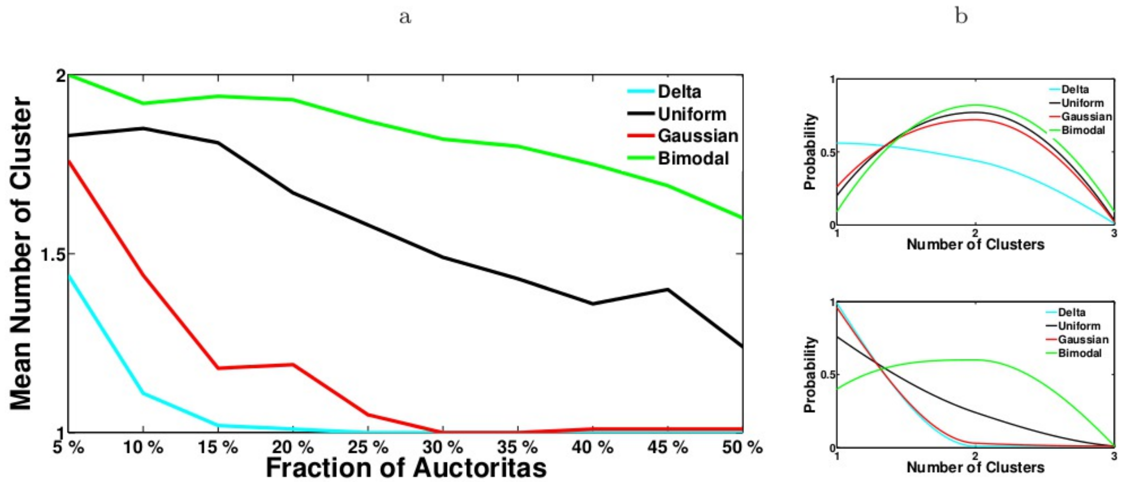

FIG. 3. Behavior of a system modulated by *auctoritates*, for four different initial distributions. a) Mean number of survived clusters at the equilibrium as a function of the fraction of *auctoritates*. b) Probability of having N clusters at the equilibrium in a single run, 5% of *auctoritates* (upper figure), 50% of *auctoritates* (lower); for sake of clearness, the histograms are interpolated by ninth degree polynomials (naturally, the effectively measured probabilities are in correspondence of integer values of the abscissas).

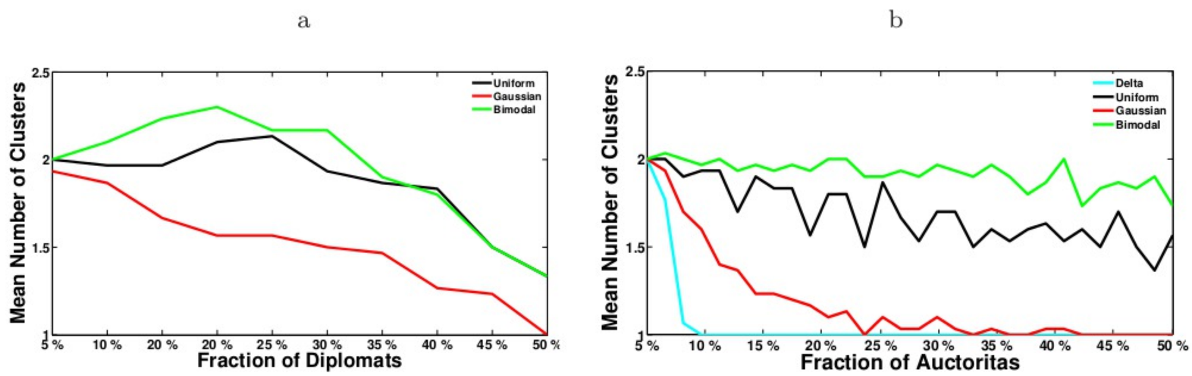

FIG. 4. Mean number of survived clusters in the final configuration as a function of the fraction of PMs, for different initial distributions of them, in case of an initially bi-clustered system. a) Acting *diplomats*; b) Acting *auctoritates*.

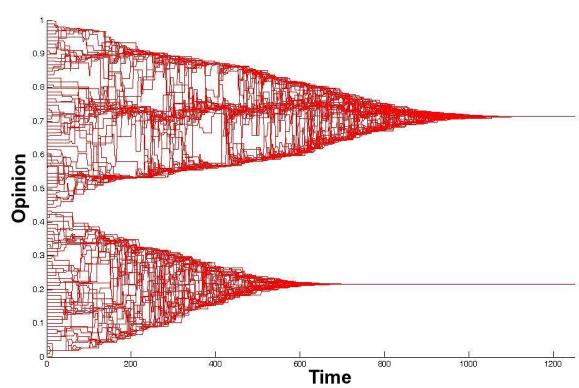

FIG. 5. Opinion trajectories for a system of $N = 100$ individuals, with 5% of *diplomats* initially uniformly distributed. In this realization, the system has ended up with two final clusters.

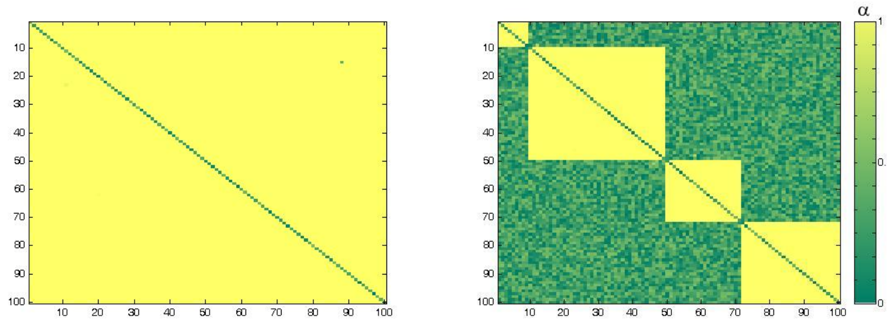

FIG. 6. Color representation of the final affinity matrices for systems of $N = 100$ individuals and 10% of initially delta-distributed *auctoritates* (left, final monocluster), and with no PMs at all (right, four final clusters). The affinities of the agents towards themselves, irrelevant for the dynamics, were set to 0.

V. THEORETICAL ANALYSIS

The dynamics of our model is complex and highly non-linear, so that it would be quite hard to get analytically the simulation results by means of a complete theoretical calculation. Anyway, it is possible to provide a qualitative justification of the behavior of the model. Let us start by considering the case of absence of any PM, that is, when every agent has the same openness of mind ΔO_c and all the affinities α_{ij} have the same (uniform) distribution $\forall i, j$. In Figure 1a an example of how dynamics takes place in this case is depicted. We can utilize a simple mean-field treatment to describe the dynamics. Therefore, said $P(x,t)dx$ the fraction of agents having an opinion in the range $[x, x+dx]$, and having in mind the definitions given in Section II, the rate equation of the distribution $P(x,t)$ is given by

$$\frac{\partial P(x,t)}{\partial t} = \int_0^1 dO \int_{|O-O'|<\frac{\sigma \Delta O_c}{1-\langle \alpha_{ij}\rangle}} dO' \; P(O,t)P(O',t) \left[\delta(x - O + \mu(O-O')) - \delta(x-O)\right] \;, \tag{7}$$

where we remind that σ is the social temperature. Analogously, it is also possible to write down an equation for the evolution of the affinities:

$$\frac{d\alpha_{ij}}{dt} = \Gamma(t) \; \alpha_{ij}[1 - \alpha_{ij}(t)] \;, \tag{8}$$

where $\Gamma(t) = \mathrm{sgn}\left(|\Delta O_{ij}(t) - \Delta O_c|\right)$. Now, let us focus on Eq. (7): it is formally completely analogous to the rate equation of the compromise model (CM) defined in [11]. In the CM two individuals interact only if their opinions differ less than 1, but the (continuous) opinions are defined up to a certain maximum value O_M. It results that the system ends up to final consensus only if $O_M < 1$: in practice, the system orders if the maximum opinion difference is not larger than the threshold for an interaction to take place. In our model $\max|O - O'|$ is of course 1, while the threshold is, in the mean-field approximation we are utilizing, $\sigma\Delta O_c/(1 - \langle\alpha_{ij}\rangle)$, which defines the integration interval of the integral in dO' in Eq. (7). Therefore, proceeding in the same way of reference [11], it becomes crucial the quantity

$$\Delta \equiv \frac{\sigma \Delta O_c}{1 - \langle \alpha_{ij}\rangle} \;, \tag{9}$$

such that if it is larger than 1 (the maximum difference possible between two opinions), the system reaches consensus, otherwise it remains disordered. Basically, in order to have final consensus it must hold

$$\Delta \geq \Delta_c = 1 \;. \tag{10}$$

The existence of this transition is confirmed in Ref. [2], even though this mean-field approximation does not catch its exact behavior. On the other hand, in Figure 1a we show the time evolution of a system with $\sigma = 0.003$, $\Delta O_c = 0.2$

and $\langle\alpha_{ij}\rangle = 0.25$ (see Ref. [2] again), that is with $\Delta = 0.0008 \ll \Delta_c$, and actually consensus is not reached, compatibly with the considerations stated above. We highlight the role of the social temperature: if $\sigma \to 0^+$, the probability of reaching consensus goes to zero (rigorously, in the limit of infinite system), because a non-zero social temperature makes two far away agents interact.

Despite the roughness of the previous calculations, this approach allows us to reckon at least qualitatively the effect of the presence of the peace mediators on the ultimate fate of the system. As a matter of fact, *auctoritates* increase the average $\langle\alpha_{ij}\rangle$, and in a similar way *diplomats* increase the average $\langle\Delta O_c^i\rangle$, which substitutes the simple ΔO_c in Eqs. (7) and (9): therefore, both make the quantity Δ of the system larger, enhancing the reaching of final consensus, as confirmed by the numerical results presented in Section IV.

VI. DISCUSSION

In the above sections we showed, both numerically and theoretically, that the presence of the PMs helps the system to reach more easily the final consensus, with respect to the model without PMs, treated in reference [2]. It results that these two kinds of special agents act differently and have different effects. More precisely, *diplomats*' effects are quite independent from their distribution throughout the population, as shown in Figure 2a, whilst *auctoritates*' action is clearly sensitive to their dislocation in the opinion space (see Figure 3a). Moreover, when the *auctoritates* are effective in favor of consensus, a smaller number of them is required with respect to the case with *diplomats*. In short, the system shows the best response in terms of final consensus when few *auctoritates* are put just in the middle of the social space of the population (*i.e.*, with opinion equal to the average of the system, in our case 0.5). These results are not in contrast with some real world features, in particular with the fact that mediators like *auctoritates* are less common but more effective than *diplomat*-like agents. Indeed, while the main characteristic of a *diplomat*, a larger openness of mind, depends only on the individual itself, acquiring authority to the others' eyes is much more difficult and does depend in general on the behavior towards other people. On the other hand, the personal prestige, once obtained, is certainly more incisive in order to persuade other individuals. For this same reason, when the *auctoritates* differ very much in opinion, they find much harder to drive the system to the consensus: as we can see in the real world, if several charismatic figures push the people towards opposite positions, usually the whole population is not able to get a general agreement.

Considering now a more theoretical point of view, as illustrated in Section V, the action of the PMs is effective because practically they help to reduce the average distance among the individuals in the opinion space. Actually, in their absence, unless all the individuals have a very high openness of mind and/or affinities towards each other, the only way to increase the probability to reduce conflict and reach consensus is to increase the social temperature, helping people to interact despite their differences, as illustrated in our previous works [2, 7]. Anyway, the social temperature must be regarded as an intrinsic property of the environment in which agents find themselves to act, and it would be difficult for whatever institution to change it in practice: on the contrary, it is clearly possible to send to the population in conflict some Peace Mediators.

Otherwise, we can wonder how to reach similar results when the dynamics of the agents is not as defined here. For instance, let us think to different types of continuous opinion models, in particular the LCCC model [12] and similar ones [13]. In these models, agents exchange their opinions, but depending on the value of a parameter called *conviction*, that is, the "inertia" an individual opposes to mind changing, the population can reach distinct final states. When the individuals have a high conviction, the system is driven to a configuration where the individuals have extreme opinions, giving birth to two totally contrasting factions. In such a case, mediators should simply aim to reduce the agents' convictions in order to reduce conflicts. With respect to these models, ours is more complex since it is defined by more parameters, but has the advantage to represent at least partially the internal dynamics of the agents' minds [14].

VII. CONCLUSIONS AND FUTURE PERSPECTIVES

In this paper we propose an application of the model of continuous opinion dynamics already introduced in [2, 6, 7], by inserting two figures of Peace Mediators, one by one either *diplomats* or *auctoritates* respectively, into a population of *normal* agents. We describe the behavior of the system in terms of opinion convergence and mean degree of fragmentation for different fraction of employed PMs, also in reference to a more likely situation, namely the case "*two opposing factions*".

The typical *modus operandi* of *diplomats* becomes more effective by inserting many of them. By referring to what we said in section III, both the insertion of few *diplomats* into groups of small size and the increase of the mean ΔO_c value of the population would lead to the same result. On the other hand, the promotion of few *auctoritates*, but in suitable positions, can assure the convergence to a widespread consensus into populations of any sort, as pointed out Sections IV and V.

The combined efforts of both the two kinds of PMs remain to be further investigated: in this paper we considered them always acting separately because our aim was the understanding of their disentangled effects, in order to evaluate more precisely their role and features. Also the effects of the population size, the time needed by such figures in order to reach the global consensus and the role of hypothetical powerful neighboring (which could have interest in fostering or hindering consensus) are still to be better understood. Finally, here we set the PMs as naturally different from the normal agents, but it could be worth to understand if they can emerge from a suitable evolutionary framework. To address all these issues, deeper studies, both of analytical and experimental nature, are needed in the next future.

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